Combined Spectral Index for Sensing the Nitrogen Status of Dryland Wheat

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Introduction

Optical sensors are now used on ground-based applicators to sense the crop and trigger nitrogen (N) applications according to the crop's potential yield response. This advanced technology relies upon the NDVI, which contrasts the reflectance in chlorophyll-absorbing red wavelengths (590 – 690 nm) with internal-leaf-scattering NIR wavelengths (780 – 1300 nm).

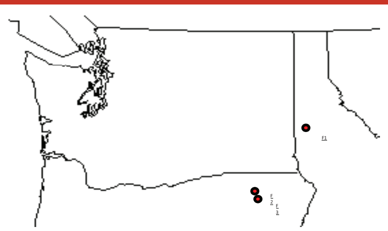
Within-field variation in red and NIR canopy reflectances, and hence NDVI, may result from spatial patterns in N deficiency, vegetation cover, leaf area index (LAI), and leaf chlorophyll a+b content. In water-limited environments, variations in LAI and cover are often linked to soil moisture rather than plant available N, which masks crop N status.

Chlorophyll indices, which utilize the spectral region between red and NIR reflectance, or red edge (690-730 nm), have been developed that are highly responsive to a wide range of chlorophyll values. These indices have proven useful for remote sensing of crop N status primarily under non-limiting water conditions where biomass is positively correlated with plant available N. However, because leaf chlorophyll indices are determined from reflectances at red and NIR wavelengths, these indices have some sensitivity to variations in LAI and cover caused by variations in soil moisture content.

Combined vegetation indices compare an index that has relatively greater sensitivity to chlorophyll with an index that has relatively greater sensitivity to LAI and cover. Recently, Eitel et al. (2007) proposed that MCARI be combined with the second Modified Triangular Vegetation Index in ratio (MCARI/MTVI2) to reduce the confounding effects of LAI on spectral estimates of chlorophyll and flag leaf N in dryland wheat.

In this study, we focus on MCARI/MTVI2 because it offered improved results over NDVI, TCARI/OSAVI, and MCARI/OSAVI. The objective of this study was to evaluate the performance of the single and combined spectral indices for ground-based sensing of chlorophyll and N status in dryland wheat production fields, where spectral variability in the visible and NIR bands is dominated by moisture rather than by N-induced variations in LAI. This information is important to suggest improvements to current ground sensing systems for use in dryland environments.

Study Sites



Hard red spring wheat was grown within three commercial dryland wheat fields: F1 near Potlatch, ID; and F2 and F3 near Helix, OR. Within each field, smaller areas of the crop were visually identified that differed in degree of greenness. Locations for sampling the crop and measuring crop reflectance were chosen randomly within dark or light colored field areas.

Location of fields, growing season rainfall, number of plots, and SPAD value with means for plots in dark-green and light-green colored areas.

Field	Location (latitude/longitude)	Mean Annual Rainfall (mm)	Number of Plots	SPAD Value†	
				Dark	Light
F1	46.96°N /116.86 °W	635	42	48.1 a	39.4 b
F2	45.81°N /118.67 °W	350	50	47.2 a	42.0 b
F3	45.84°N /118.68 °W	350	52	46.9 a	41.8 b

Canopy Reflectance Modelling

Prospect-SAIL radiative transfer model was used to simulate leaf Reflectance and transmittance spectra between 500 and 900 nm At a spectral resolution of 1 nm. Model input parameters included:

Parameter	Value
Soil reflectance	Soil reflectance of bare dry soil measured at F1
Latitude	46.70°
Solar declination angle	22.53°
Leaf angle distribution	Spherical
Sensor viewing angle	0° (nadir)
Sensor zenith angle	0° (nadir)
Time of day	12
Fraction direct solar	1
Leaf optical properties	Simulated reflectance and transmittance (PROSPECT) with varying C_{ab} content from 20 to 80 μg cm^{-2} in 5 μg cm^{-2} steps
Leaf area index (LAI)	1.0 to 5.0 (in 0.25 LAI steps) and 5.0 to 6.5 (in 0.5 LAI steps)

Reflectance data simulated by Prospect-SAIL were used to compute various single and combined spectral indices.

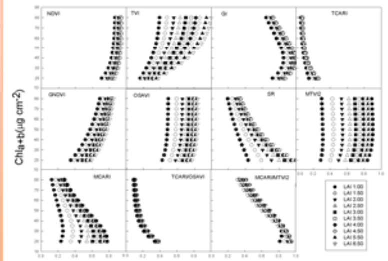
Vegetation Index	Equation	Reference
	Structural Indices	
Normalized Difference Vegetation Index (NDVI)	$NDVI = (R_{band4} - R_{band2})/(R_{band4} + R_{band2})$	Rouse et al. (1974)
Green Normalized Difference Vegetation Index (GNDVI)	$GNDVI = (R_{band4} - R_{band1})/(R_{band4} + R_{band1})$	Gitelson and Merzlyak (1998)
Optimized Soil Adjusted Vegetation Index (OSAVI)	$OSAVI = (1 + 0.16) * (R_{band4} - R_{band2})/(R_{band4} + R_{band2} + 0.16)$	Rondeaux et al. (1996)
Simple Ratio (SR)	$SR = (R_{band4}/R_{band2})$	Rouse et al. (1974)
Second Modified Triangular Vegetation Index (MTVI)	$MTVI2 = (1.5[1.2(R_{band4}-R_{band1})-2.5(R_{band2}-R_{band1})]/[(2R_{band4}+1)2-(6R_{band4}-5_{band2}{}^{1/2})-0.5]^{1/2}$	Haboudane et al. (2002)
	Chlorophyll Indices	
Green Index	$GI = (R_{band1}/R_{band2})$	
Triangular Vegetation Index (TVI)	$TVI = 0.5*[120*(R_{band3}-R_{band1})-200*(R_{band2}-R_{band1})]$	Broge and Leblanc (2000)
Modified Chlorophyll Absorption in Reflectance Index (MCARI)	$MCARI = [(R_{band3} - R_{band2})-0.2*(R_{band\,3}-R_{band\,1})](R_{band\,3}/R_{band\,2})$	Daughtry et al. (2000)
Transformed Chlorophyll Absorption in Reflectance Index (TCARI)	$TCARI = 3*[(R_{band3} - R_{band2}) - 0.2 * (R_{band3} - R_{band1}) * (R_{band3}/R_{band2})]$	Haboudane et al. (2002) Barnes et al. (2000)
Normalized Red Edge Difference (NDRE)	$NDRE = (R_{band4} - R_{band3})/(R_{band4} + R_{band3})$	
	Combined Indices	
	TCARI/OSAVI	Haboudane et al. (2002)
	MCARI/MTVI2	Eitel et al. (2007)
	NDRE/NDVI	Barnes et al. (2000)

Field Measurements

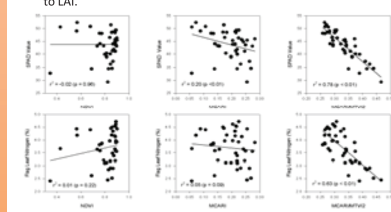
Test measurements of crop reflectance were obtained in farm fields with an ASD FieldSpec Pro radiometer.

Reference measurements of relative chlorophyll were taken using a SPAD chlorophyll meter. Flag leaves were sampled for laboratory analysis of N concentration. Leaf area index was also measured using a LICOR Crop Canopy Analyzer.

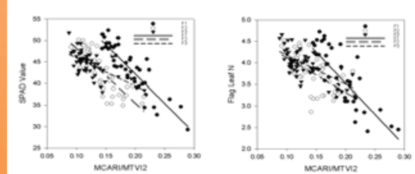
Results



Simulated vegetation indices as a function of chlorophyll and LAI. Index MCARI/MTVI2 was both sensitive to chlorophyll and resistant to LAI.



Relationships between spectral indices (NDVI, MCARI, and MCARI/MTVI2), and SPAD value or flag leaf N in F1. MCARI/MTVI2 was highly correlated with SPAD chlorophyll and flag leaf N.



Regression relationships between MCARI/MTVI2, and SPAD value or flag leaf N in each field. Relationships varied with geographic location.

Conclusions

NDVI using NIR, and red or green reflectance will be poorly related with chlorophyll or flag leaf N in dryland environments.

This inability is due to sensitivity to LAI, which confounds predictions of crop N status, and thus limits usefulness of NDVI-based sensing under dryland conditions.

Use of these systems would be better undertaken in irrigated fields that offer canopy closure.

A combined index such as MCARI/MTVI2 will improve multispectral reflectance estimates of wheat N status under dryland field conditions.

(1) Sensitive to chlorophyll; resistant to LAI.

(2) Accommodate soil variability thereby minimizing need for reference strips.

(3) Improvements to sensor systems.

References

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